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Progress in Unsteady Turbopump Flow Simulations Using Overset Grid Systems

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1

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Outline

- INTRODUCTION
  - Major Drivers of the Current Work
  - Objective
- SOLUTION METHODS
  - Summary of Solver Development
  - Formulation / Approach
  - Parallel Implementation
- UNSTEADY TURBOPUMP FLOW
  - Overset Grid System
  - Scripting Capability
  - Results
- SUMMARY

2

Objectives

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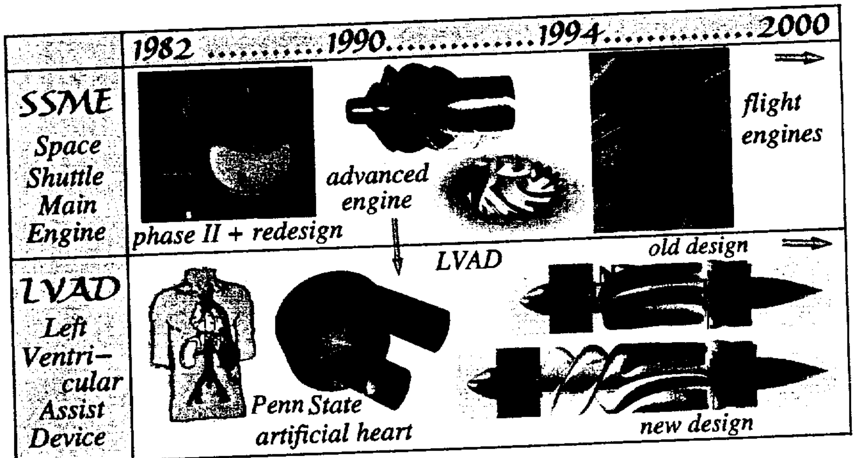
- To enhance incompressible flow simulation capability for developing aerospace vehicle components, especially, unsteady flow phenomena associated with high speed turbo pump.



Current Challenges

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- Challenges where improvements are needed
  - Time-integration scheme, convergence
  - Moving grid system, zonal connectivity
  - Parallel coding and scalability
- As the computing resources changed to parallel and distributed platforms, computer science aspects become important.
  - Scalability (algorithmic & implementation)
  - Portability, transparent coding, etc.
- Computing resources
  - "Grid" computing will provide new computing resources for problem solving environment
  - High-fidelity flow analysis is likely to be performed using "super node" which is largely based on parallel architecture

4

Time Accurate Formulation

- Time-integration scheme

Artificial Compressibility Formulation

· Introduce a pseudo-time level and artificial compressibility
· Iterate the equations in pseudo-time for each time step until incompressibility condition is satisfied.

Pressure Projection Method

· Solve auxiliary velocity field first, then enforce incompressibility condition by solving a Poisson equation for pressure.

5

INS3D - Incompressible N-S Solver

** *Parallel version is based on* INS3D-UP :

- MPI and MLP parallel versions
- Structured, overset grid orientation
- Moving grid capability
- Based on method of artificial compressibility
- Both steady-state and time-accurate formulations
- 3rd and 5th-order flux difference splitting for convective terms
- Central differencing for viscous terms
- One- and two-equations turbulence models
- Several linear solvers : GMRES, GS line-relaxation, LU-SGS, GS point relaxation, ILU(0)..,..

- HISTORY
  - ** 1982-1987 Original version of INS3D - Kwak, Chang
  - ** 1988-1999 Three different versions were devoped :
    - INS3D-UP / Rogers, Kiris, Kwak
    - INS3D-LU / Yoon, Kwak
    - INS3D-FS / Rosenfeld, Kiris, Kwak

6

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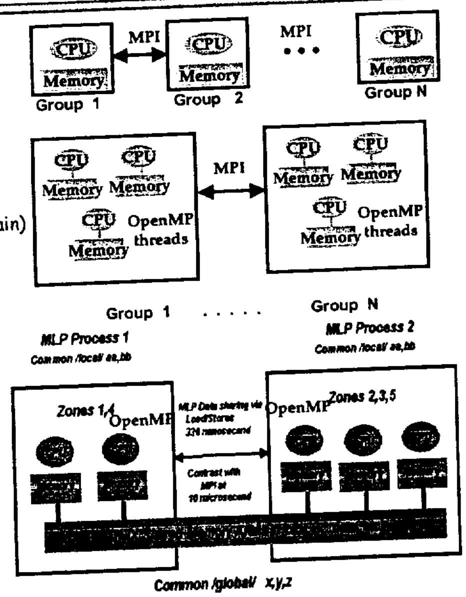
INS3D Parallelization

- INS3D-MPI
  (coarse grain)
- INS3D-MPI / Open MP
  MPI (coarse grain) + OpenMP (fine grain)
  Implemented using CAPO/CAPT tools
- INS3D-MLP



7

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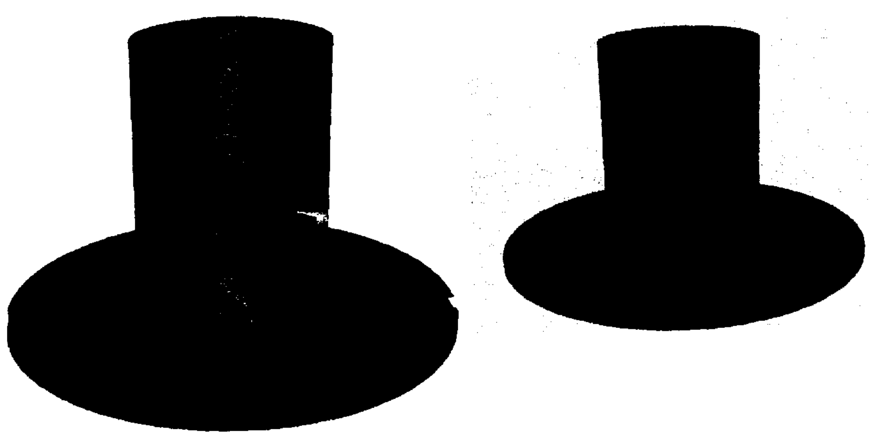
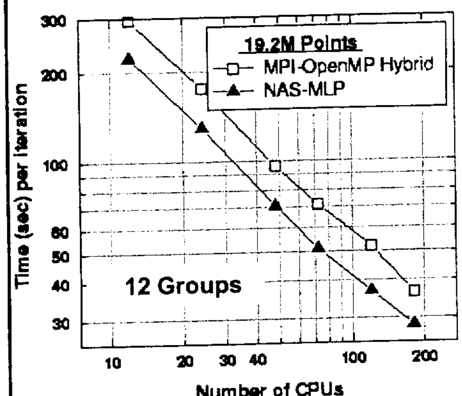


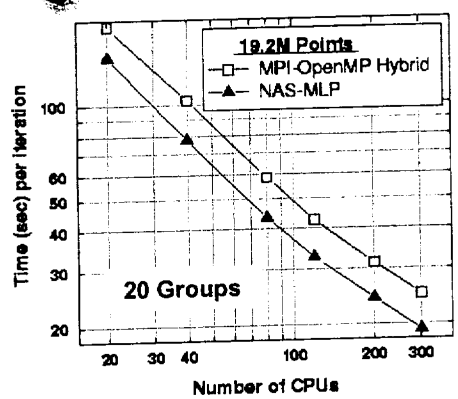
8

INS3D Parallelization

INS3D-MLP/OpenMP vs. -MPI/OpenMP

TEST CASE : SSME Impeller
60 zones / 19.2 Million points

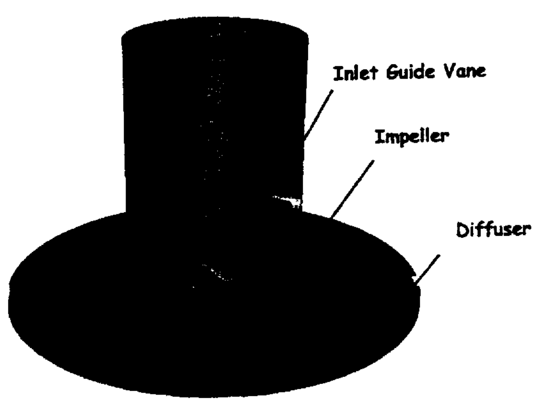


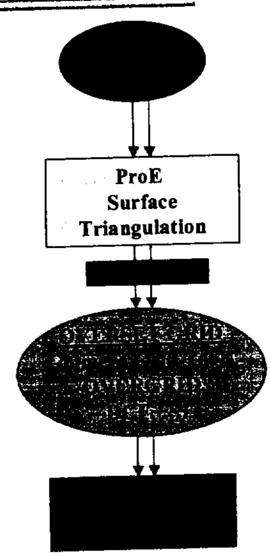


9

RLV 2nd Gen Turbopump (SSME Rig1)

Impeller Technology Water Rig
Baseline SSME/ATD HPFTP Class Impeller

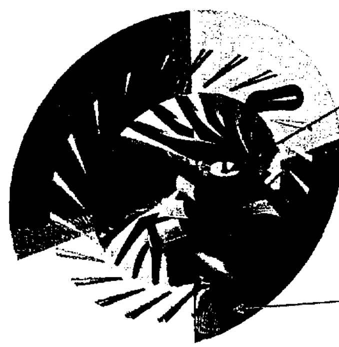




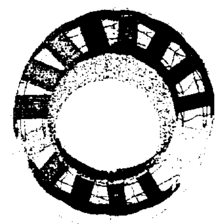
10

RLV 2nd Gen Turbopump

Overset Grid System



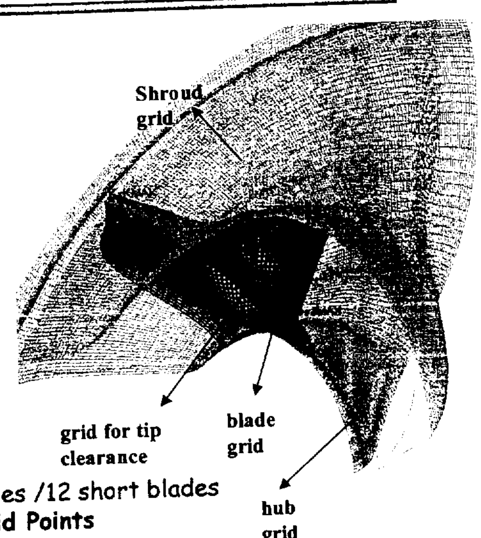
Inlet Guide Vanes
15 Blades
23 Zones
6.5 M Points



Diffuser
23 Blades
31 Zones
8.6 M Points

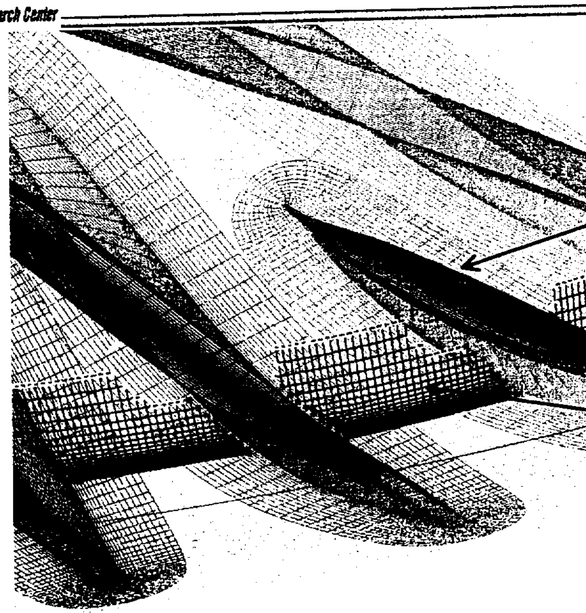
11

RLV 2nd Gen Turbopump



Unshrouded Impeller Grid :
6 long blades / 6 medium blades /12 short blades
60 Zones / 19.2 Million Grid Points
Overset connectivity : DCF (B. Meakin)
Less than 156 orphan points.

Impeller Overset Grid System



Blade Grid

Background Grid

13

RLV 2nd Gen Turbopump

Particle traces and pressure surface at the end of first rotation.

14

RLV 2nd Gen Turbopump

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15

RLV 2nd Gen Turbopump

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16

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RLV 2^{nd} Gen Turbopump

17

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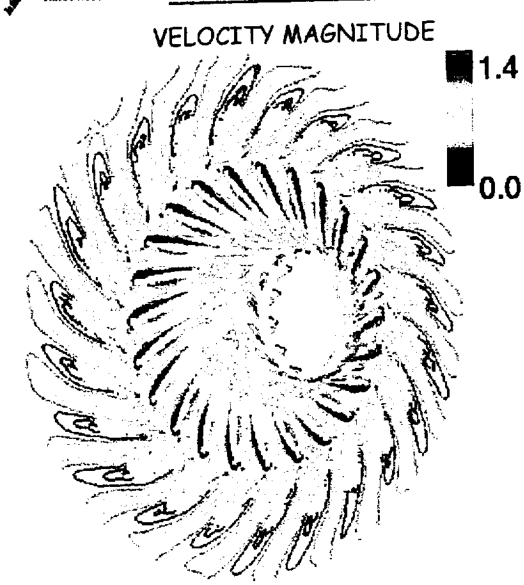
RLV 2^{nd} Gen Turbopump



- 34.3 Million Points
-Three impeller rotations are completed.

•One complete rotation requires less then 3.5 days by using 128 CPUs on SGI Origin 3000. When 512 CPUs are utilized one rotation can be completed less then 1.5 days. In 1999, one impeller rotation would take 42 days by using 32 CPUs on SGI Origin 2000 platform.

RLV 2nd Gen Turbopump

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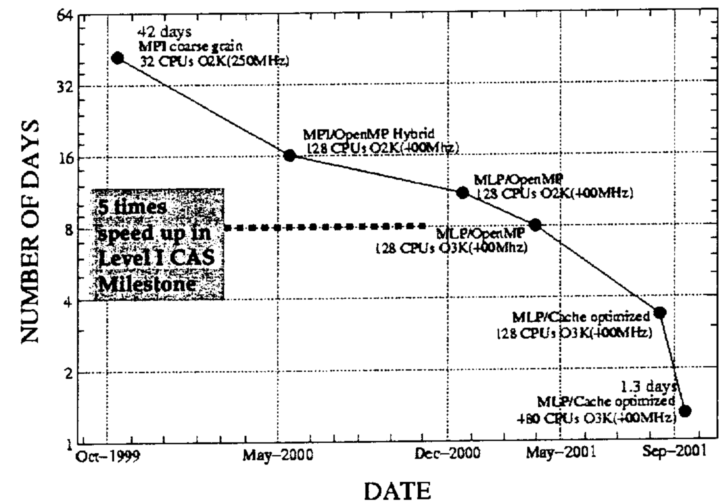
34.3 Million Grid points RLV Turbopump one impeller rotation



19

RLV 2nd Gen Turbopump

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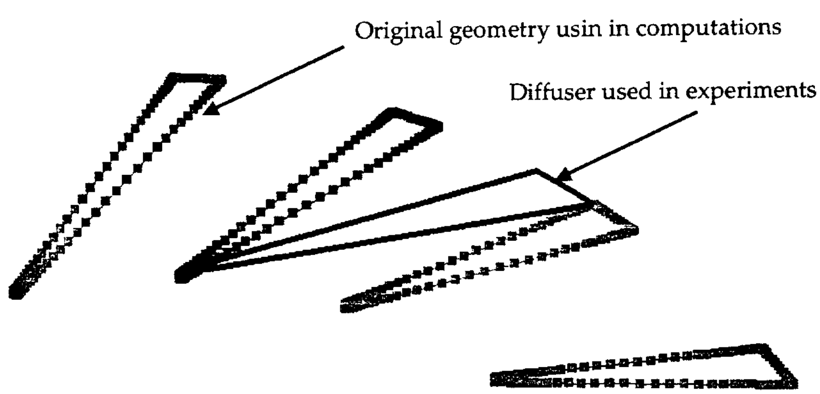
Diffuser blade needs to be corrected to compare with experiments



20

Scripting Capability

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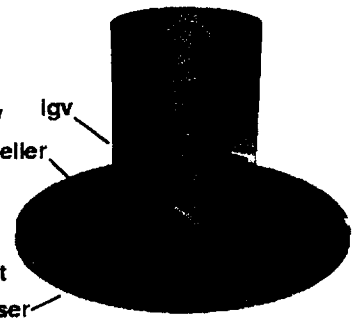
SCRIPT DEVELOPMENT FOR TURBOPUMP SIMULATIONS

Motivation

Significant user's effort needed in complex process from geometry to flow solver



Objective

Develop script system to
- generate grids
- create domain connectivity input
- create flow solver input

for different components automatically

GEOMETRY → Turbopump Scripts → DCF → FLOW SOLVER

Turbopump Scripts → grids | domain connectivity input | flow solver input

Approach

Develop one script for each component with ring interface between components => easy plug in for different designs and combinations of components

21

Scripting Capability

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SCRIPT GENERATION

Disadvantages

> Require expertise to build scripts the first time

Advantages

> Allow rapid re-run of entire process

> Easy to do grid refinement and parameter studies

> Easy to try different gridding strategies

> Documentation of gridding procedure

Tcl scripting language

> Works on UNIX, LINUX and WINDOWS

> Integer and floating point arithmetic capability

> Modular procedure calls

> Easy to add GUI later if needed

22

Scripting Capability

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INPUT AND OUTPUT

Input

> profile curves for hub and shroud in PLOT3D format (rotated by script to form surface of revolution)

> blade and tip surfaces in PLOT3D format

> Parameters that can be changed
– number of blades and sections
– global surface grid spacing Δs (on smooth regions)
– local surface grid spacing, some independent and some expressed as multiples of Δs (leading/trailing edges, etc.)
– normal wall grid spacing (viscous, wall function)
– marching distance
– grid stretching ratio
– ...

Output

> overset surface and volume grids for hub, shroud, blades
> object X-rays for hole cutters using DCF
> domain connectivity namelist input for OVERFLOW-D

23

Scripting Capability

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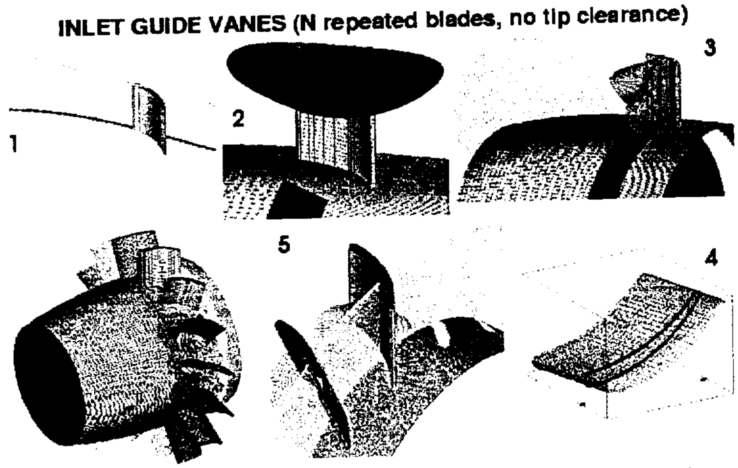
INLET GUIDE VANES (N repeated blades, no tip clearance)



	Manual	Script (fine)	Script (coarse)
No. of pts (million)	7.1	5.8	1.1
User time *	1 day	43 sec.	20 sec.

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

24

Scripting Capability

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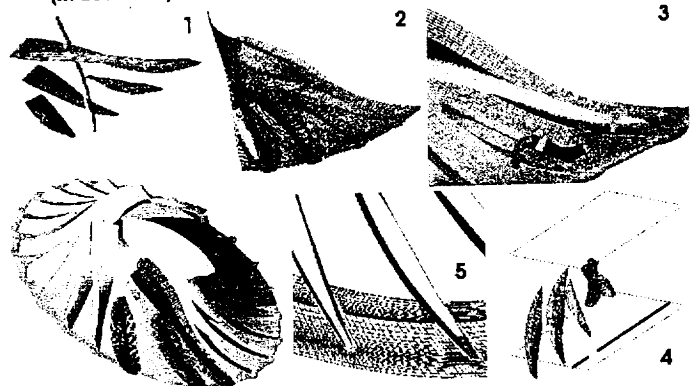
IMPELLER
(M sections, N different blades in each section, tip clearance)



	Manual	Script (fine)	Script (coarse)
No. of pts (million)	19.2	15.2	8.8
User time *	~ 2 weeks	319 sec.	234 sec.

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

25

Scripting Capability

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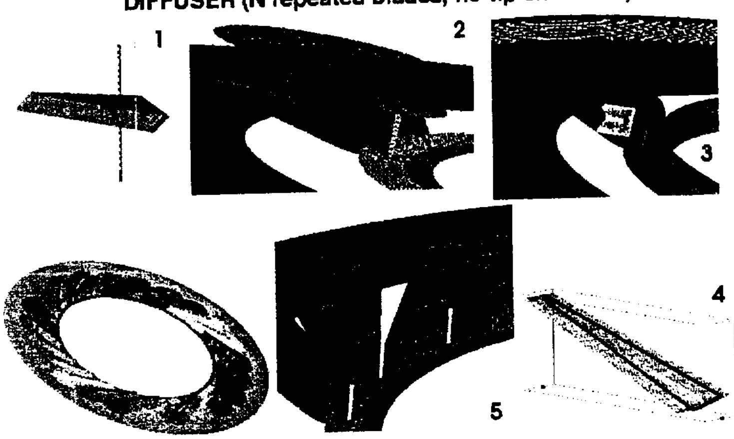
DIFFUSER (N repeated blades, no tip clearance)



	Manual	Script (fine)	Script (coarse)
No. of pts (million)	8.0	6.4	1.6
User time *	1 day	37 sec.	22 sec.

(* from geometry def. to DCF input with SGI R12k 300MHz CPU)

26

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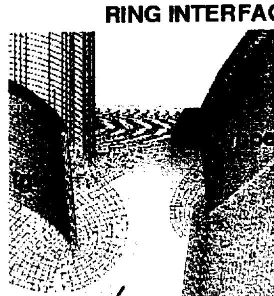
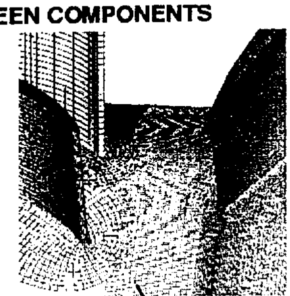
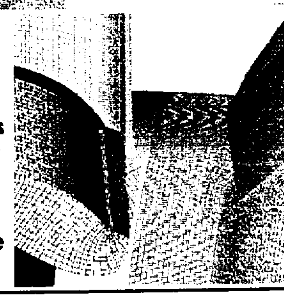
RING INTERFACE BETWEEN COMPONENTS





Igv out ring

Impeller in ring



- **> 9–point overlap between rings**
- **> no impeller points beyond last plane of igv ring**
- **> no igv points beyond first plane of impeller ring**

2

Scripting Capability

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FUTURE PLANS FOR TURBOPUMP SCRIPTING

- **> Flow solver input creation in scripts**
- **> Develop master script for connecting different components**
- **> Develop script for other components, e.g., volute, inducer**
- **> Perform more tests on different parameters**
- **> Improve robustness (error traps, wider range of cases)**
- **> Graphical interface front end**

28

Consortium Impeller-Diffuser

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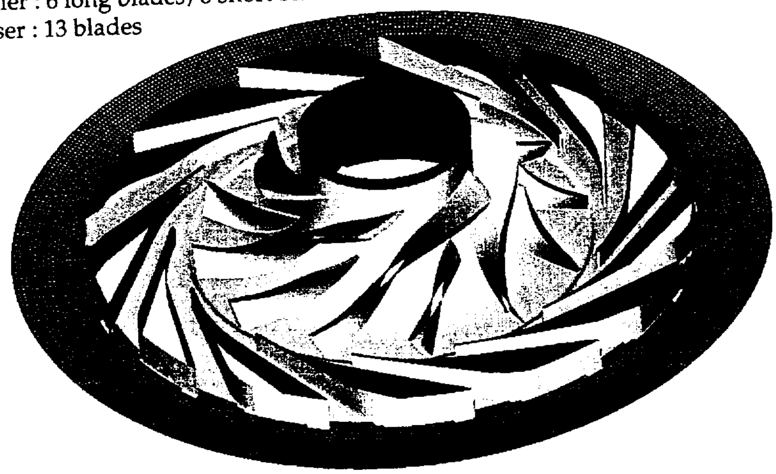
-Geometry and operating conditions obtained on January 24, 2002
(M. Williams @ Boeing , and D. Dorney NASA-MSFC)
-Impeller : 6 long blades/6 short blades
-Diffuser : 13 blades



29

Consortium Impeller-Diffuser

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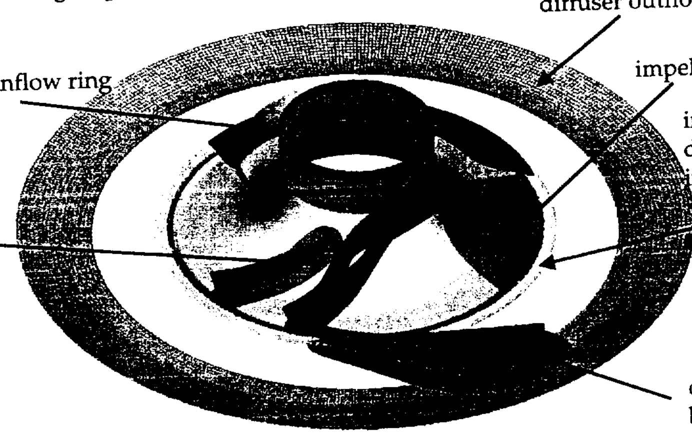
-Rotational speed :6322 RPM / Mass Flow Rate : 1210 gallons/min.
-Re : 1.37×10^{7} / $L_{ref} = 4.5225$ inches, $V_{ref} = V_{tip} = 249.5$ ft/sec
-39 Million grid points / 41 zones in overset grid systems



30

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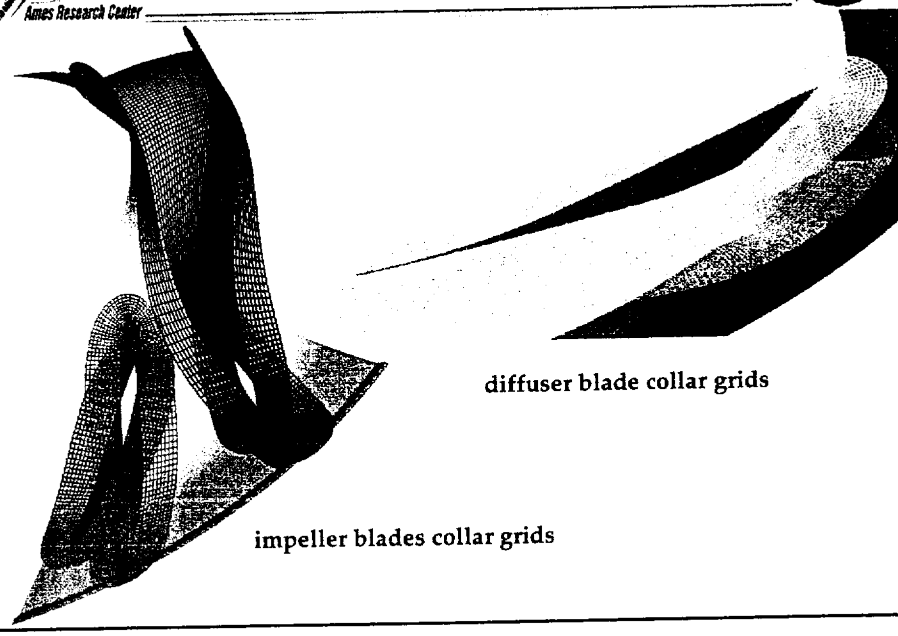
Consortium Impeller-Diffuser



diffuser blade collar grids

impeller blades collar grids

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Consortium Impeller-Diffuser

Impeller – diffuser interaction

32

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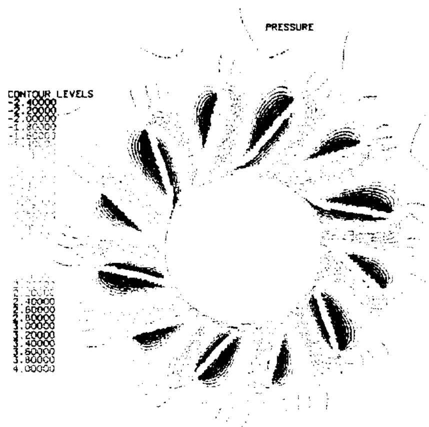
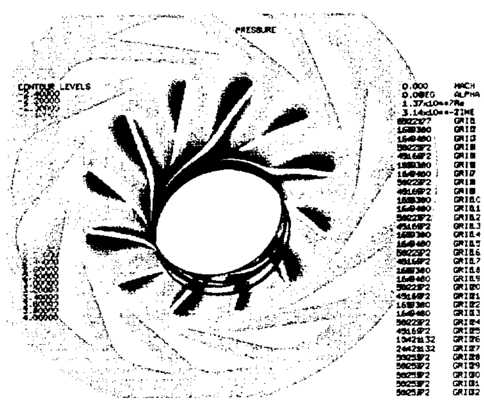
INITIAL START / Impeller started rotating at design speed
pressure contours and surfaces





33

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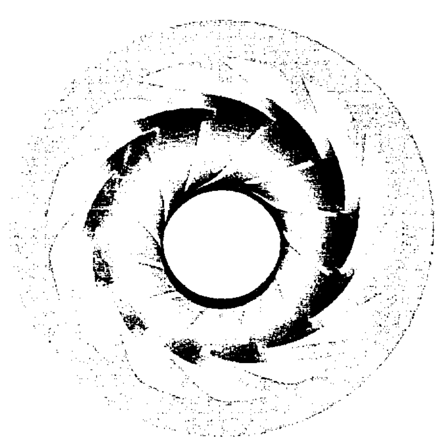
First Rotation : Impeller rotated 90 degrees.

pressure surfaces



total velocity surfaces

34

Consortium Impeller-Diffuser

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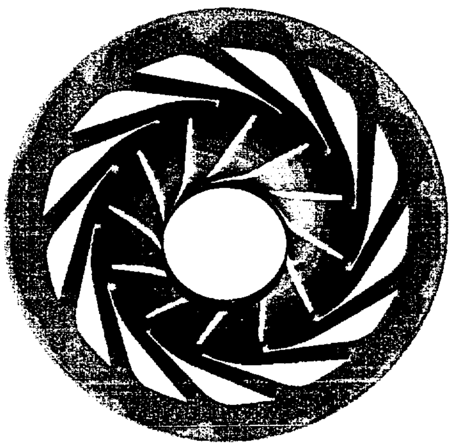
First Rotation : Impeller rotated 160 degrees.

pressure surfaces



total velocity surfaces

35

Consortium Impeller-Diffuser

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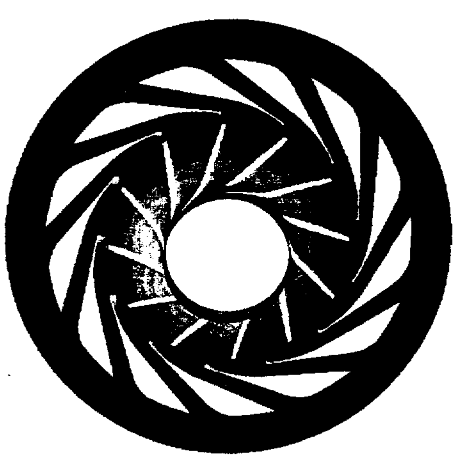
First Rotation : Impeller rotated 240 degrees.

pressure surfaces



total velocity surfaces

36

Consortium Impeller-Diffuser

First Rotation : Impeller rotated 360 degrees.

pressure surfaces

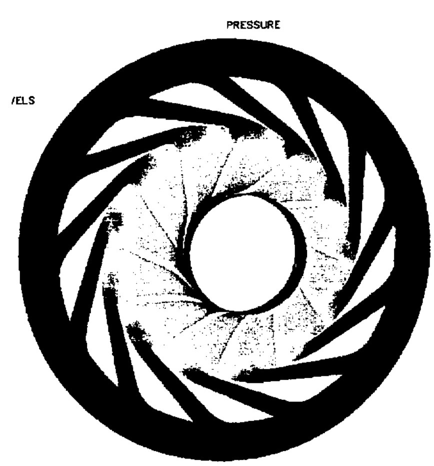
total velocity surfaces

37

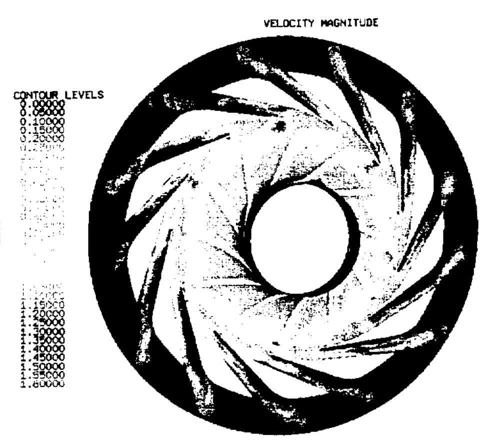
Consortium Impeller-Diffuser

Second Rotation : t/T = 1.2

pressure surfaces



total velocity surfaces



38

Consortium Impeller-Diffuser

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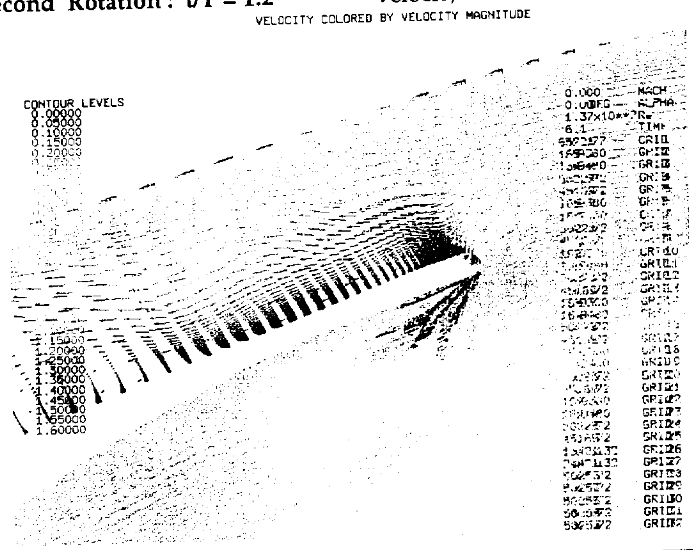
Second Rotation : t/T = 1.2 velocity vectors near diffuser blade



39

Consortium Impeller-Diffuser

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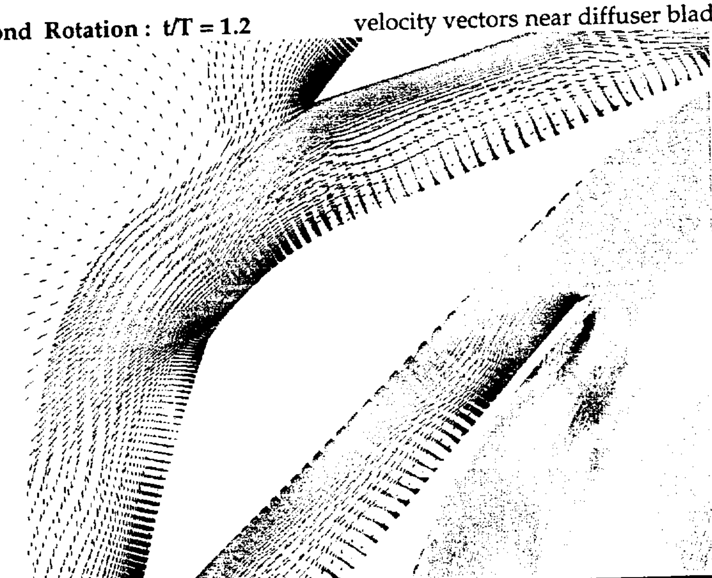
Second Rotation : t/T = 1.2 velocity vectors near diffuser blade



40

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STATIC/DYNAMIC STRESS ANALYSIS FOR TURBOPUMP SUB-SYSTEMS

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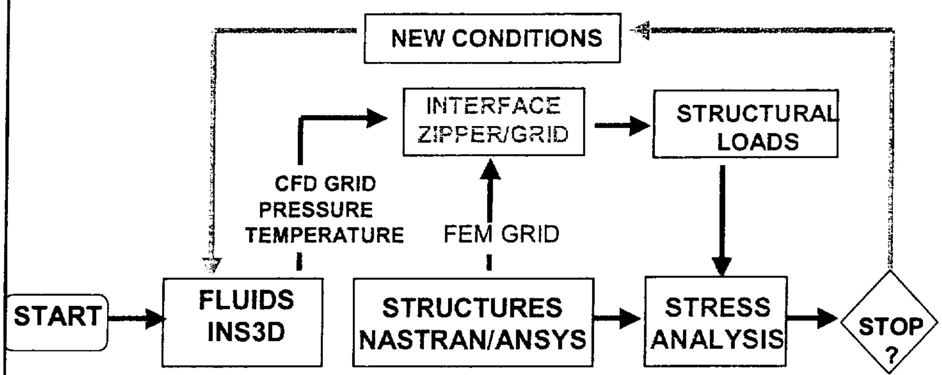

41

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Summary

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- Unsteady flow simulations for RLV 2nd Gen baseline turbopump for three impeller rotations are completed by using 34.3 Million grid points model.

- MPI/OpenMP hybrid parallelism and MLP shared memory parallelism has been implemented in INS3D, and benchmarked.

- For RLV turbopump simulations more than 30 times speed-up has been obtained.

- Moving boundary capability is obtained by using DCF module.

- Scripting capability from CAD geometry to solution is developed.

- Unsteady flow simulations for advanced consortium impeller/diffuser by using 39 Million grid points model are currently underway. 1.2 impeller rotations are completed.

- Fluid/Structure coupling is initiated.

42